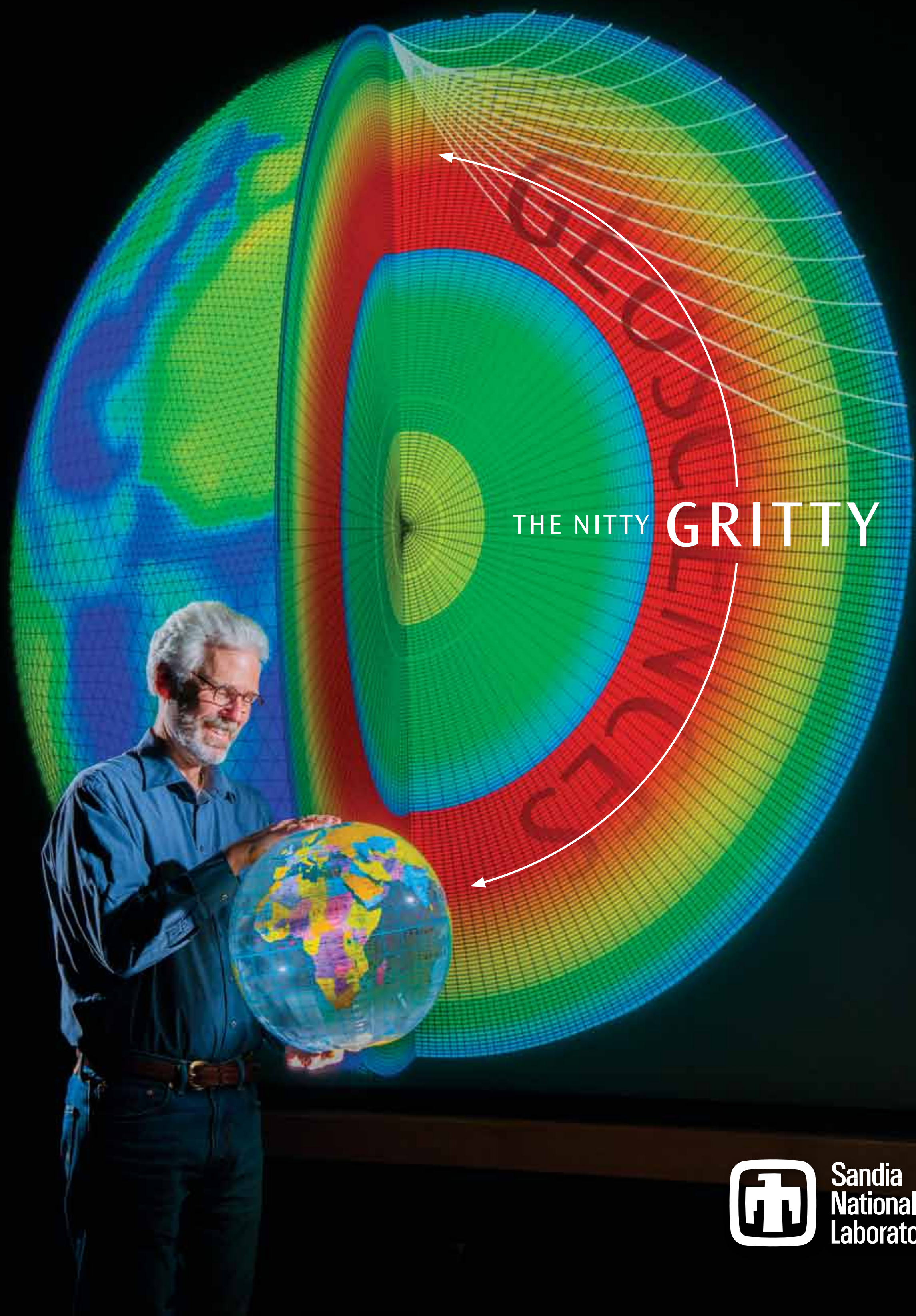
Sandia RESEARCH

September 2013 • Vol 1, Issue 3



THE NITTY GRITTY

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Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. Sand No. 2013-7412P. MV.

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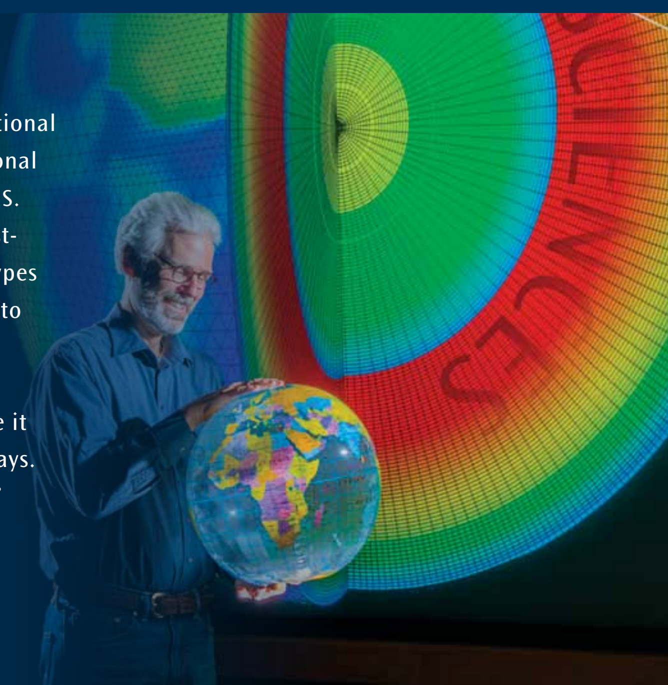

Sandia researcher Sandy Ballard holds the world in his hands. He and colleagues at Sandia and Los Alamos national laboratories have developed SALSA3D, a three-dimensional model of the Earth's mantle and crust that helps the U.S. Air Force and International Comprehensive Nuclear-Test-Ban Treaty Organization pinpoint the locations of all types of explosions. SALSA3D reduces uncertainty, important to decision-makers who must take action when suspicious activity is detected. "When you have an earthquake or nuclear explosion, not only do you need to know where it happened, but also how well you know that," Ballard says. "Getting it done is hard, and we've accomplished that."

(Photo by Randy Montoya)

Table of Contents

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Sandia RESEARCH

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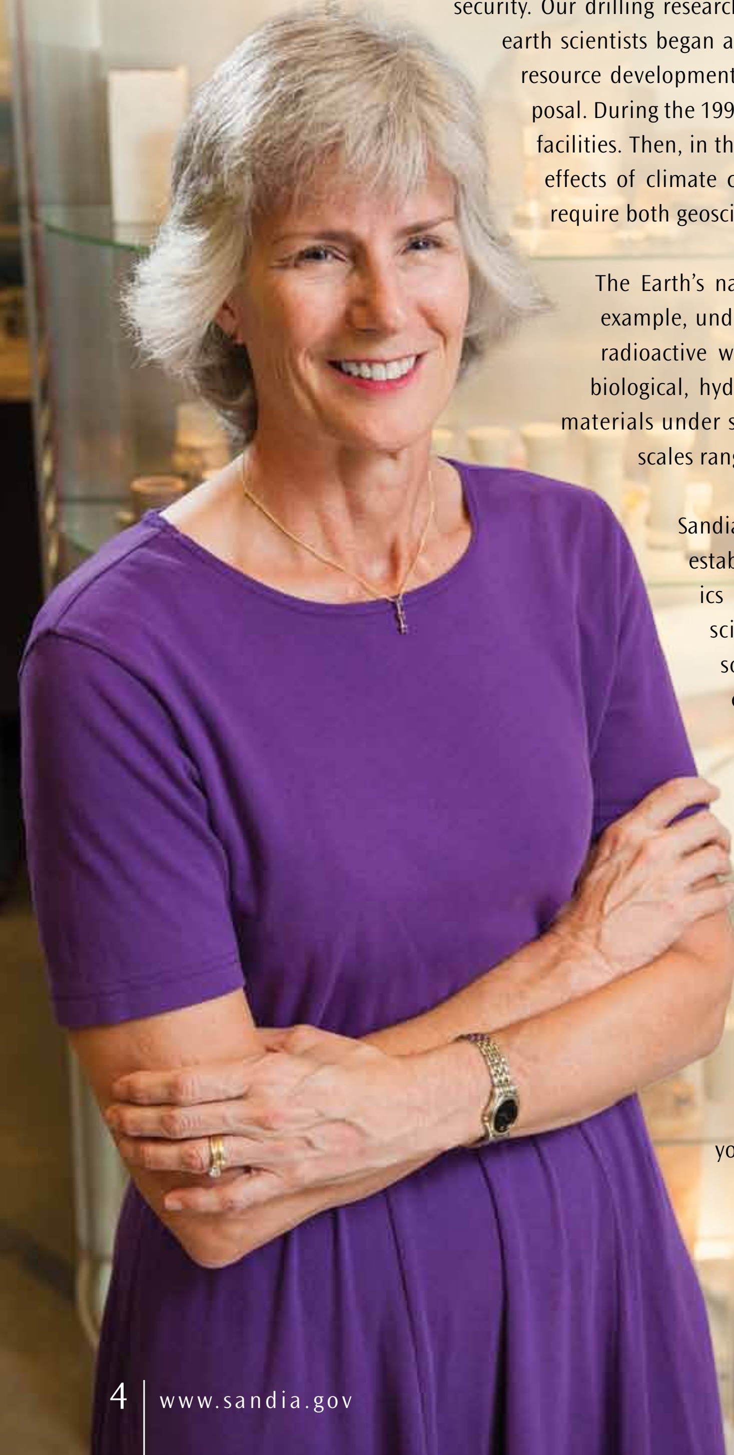
EARTH MEETS ENGINEERING

In 1959, Sandia hired its first geophysicist to conduct earth science research for national security applications. As the nation's needs have evolved, so has our research.

Sandia's geoscience research in the 1960s focused on the effects of atmospheric and underground nuclear weapons testing. That quickly evolved into methods to determine the size of the weapons' seismic yield and into global monitoring of nuclear tests for treaty verification. In the 1970s, we were asked to apply that knowledge to energy security. Our drilling research turned to geothermal energy applications and our earth scientists began addressing energy issues associated with fossil energy resource development, underground storage of oil and nuclear waste disposal. During the 1990s, our attention focused on clandestine underground facilities. Then, in the 2000s, carbon sequestration and understanding the effects of climate change became a concern. These kinds of problems require both geoscience and engineering expertise.

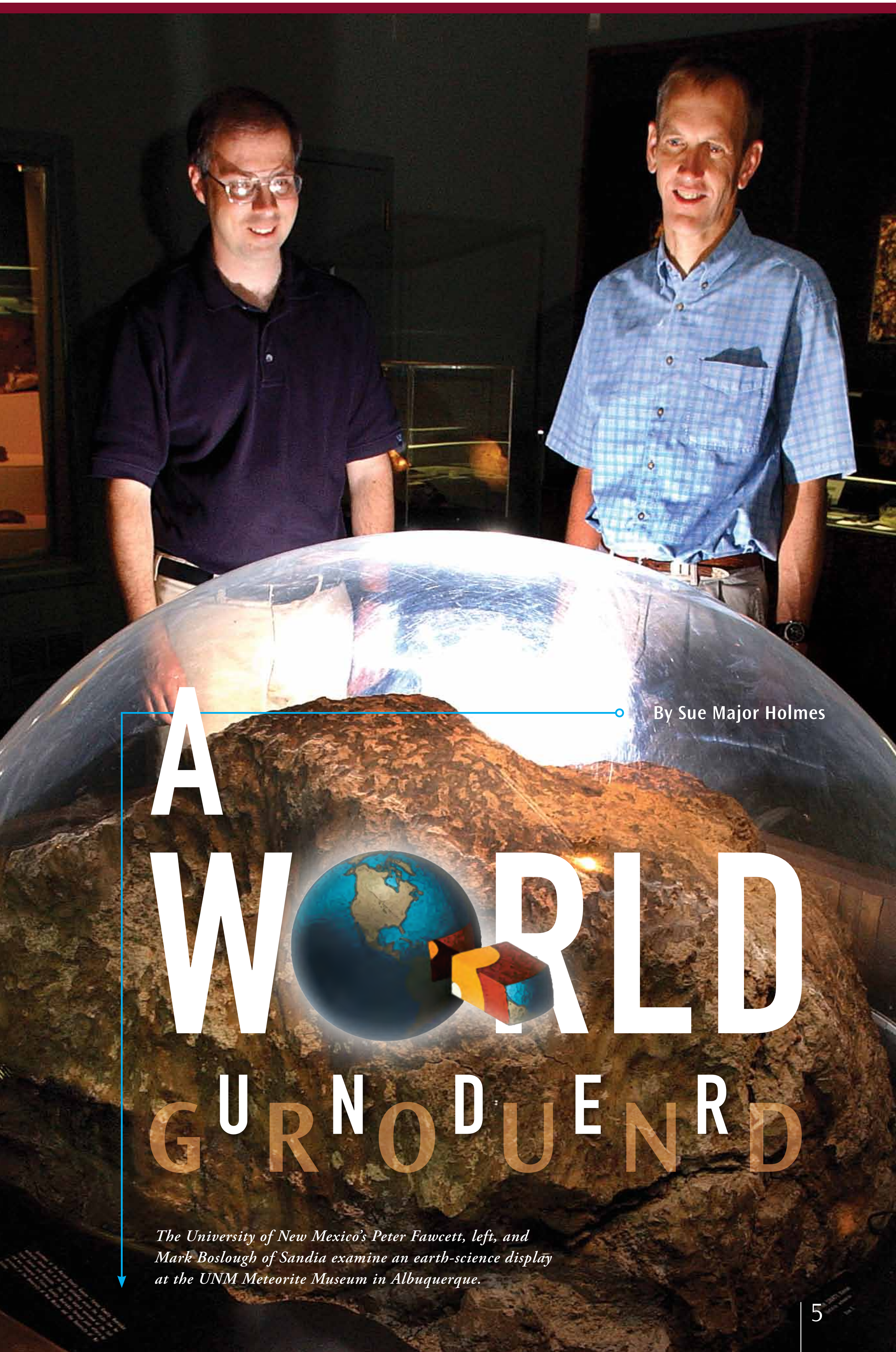


The Earth's natural systems provide a number of challenges. For example, understanding the subsurface environment used to store radioactive waste or carbon dioxide involves thermal, chemical, biological, hydrological and mechanical behavior of very different materials under stress. Further, underground processes are active at scales ranging from mere nanometers to many kilometers.

Sandia's deep geoscience expertise combined with our established strengths in engineering science, mathematics and computing, sensor development and materials science provide the tools and knowledge needed to solve complex problems that involve the Earth and engineered systems. Our geomechanics, drilling and atmospheric science research facilities also provide scientists unique experimental opportunities.

In this issue of *Sandia Research*, we give readers a window into our portfolio of geoscience work that spans fundamental science to high-tech applications. The cover story shows the breadth of our research and the accompanying pieces introduce you to some of our researchers and the leading-edge projects they are working on. Geoscience expertise is essential to the safety and security of the United States and its citizens. We hope you see why in these pages.

Marianne Walck
Director
Geoscience Research Foundation



A WORLD UNDERGROUND

By Sue Major Holmes

The University of New Mexico's Peter Fawcett, left, and Mark Boslough of Sandia examine an earth-science display at the UNM Meteorite Museum in Albuquerque.

SCIENTISTS WHO CRACKED THE SURFACE OF EARTH UNCOVERED A WEALTH OF RESOURCES. IT'S A SURPRISING PLACE WHERE ENGINEERING HAS IMPACT.

Humans have turned to the Earth since ancient times when salt was the basis of wealth. And as people developed more natural resources, geosciences grew out of their need to figure out how to work with Earth's riches.

Today, the Geosciences Research Foundation at Sandia National Laboratories delves into everything from probing geologic formations for oil or nuclear waste storage to creating instruments and computer codes to address the problems that arise when human and Earth systems intersect.

"The Earth surprises us all the time. A lot of it is because the Earth's dynamic," says Marianne Walck, foundation lead director. "That's why it's so fascinating."

Sandia's geologic know-how arose from the nation's underground nuclear testing program. Research has expanded since, and foundation scientists, drawing on expertise throughout Sandia, study salt, sandstone, shale and volcanic rocks. They look into radioactive waste storage, oil and gas extraction technologies and carbon sequestration as part of the labs' missions of energy and nuclear waste storage. They've researched bedded salt for WIPP, the Waste Isolation Pilot Plant near Carlsbad, N.M.; volcanic tuff for the once-proposed Yucca Mountain repository for high-level waste; salt domes for the Strategic Petroleum Reserve (SPR); shale for shale gas production; and sandstones to store carbon dioxide (CO_2) deep underground.

Walck says Sandia's advantage in handling geosciences problems is its broad experience. "That's why our combination of people at Sandia who do sensors, who do geology, who do atmospheric science, who do mechanics, who do computer science — you can put them all together and tackle these problems."

ANCIENT BURIAL CHAMBER

Some of Sandia's longest-running work has been for the Waste Isolation Pilot Plant, or WIPP, where it has been science adviser for decades. WIPP, which holds waste contaminated with plutonium and other transuranic elements from the nation's defense program, was excavated from the vast, ancient salt beds of southeastern New Mexico. The facility in a 16-square-mile area withdrawn from public use excavates storage rooms about 2,100 feet below the surface, with nearly 1,000 feet of salt beneath the repository. The National Academy of Sciences identified salt as a possible medium for nuclear waste disposal in 1957. Studies began in New Mexico in the mid-1970s.

WIPP mining crews excavate disposal rooms for transuranic radioactive waste in salt formations 2,150 feet underground.

Photo courtesy of U.S. DOE Carlsbad Field Office

Sandia scientists and engineers helped select the site for WIPP, provided the facility's conceptual design and supplied the scientific understanding that formed the basis for Environmental Protection Agency certification in 1999. The nation's first underground repository for nuclear waste left over from the Cold War was constructed in salt beds near Carlsbad, N.M.

"The beauty of salt is it's a natural material but it has the engineering properties that are nearly perfect for the encapsulation of nuclear waste," says Frank Hansen of Sandia's Geosciences Research and Applications Department.

Pressure deforms WIPP's storage rooms. Ceilings collapse and walls and floors buckle inward. The first WIPP rooms were excavated in 1988 but the repository didn't open until 1999, giving researchers the opportunity to monitor deformation in a disposal chamber.

Hansen says disposal rooms closed about 25 percent in a decade. That rate won't hold true for every room because the creep of the salt depends on a room's shape, size and arrangement, but the experience offered insights, he says.

Before WIPP could open, the Environmental Protection Agency required it to have a shaft sealing system for the eventual closure of the repository. Sandia's sealing design consists of three primary elements: bentonite on the bottom, reconsolidated salt in the middle and salt-saturated concrete along the salt column in the shaft.

Bentonite is naturally impermeable clay that swells when wet. It's familiar as cat litter, but it's also famous in repository sciences as a plug. Sandia developed the next layer, reconsolidated salt. Experiments compacted salt from WIPP's excavation into a large container and "squeezed it up like Mother Earth" in a lab, then researchers studied the atomic structure with optical and scanning electron microscopy, Hansen says. The final layer, salt-based concrete, represents what he calls a regular civil engineering material in a salt environment. Sandia saturated the water-cement ratio with sodium chloride for an impermeable material. ■

SALT, TAKE A BOW

Sandia's work on understanding salt began decades ago because of government interest in salt as a medium for underground testing, says Geotechnology and Engineering Department manager Dave Borns. Sandia brought its expertise in salt science to WIPP in 1976 and to the Strategic Petroleum Reserve (SPR) later that decade.

Salt is important as a repository medium because of its low permeability; it traps fluids. It costs much less than building storage tanks, has a longer lifespan and it's easy and relatively cheap to mine, Borns says.

Steve Bauer of Sandia's Geomechanics Department says cavern builders plan on a 30-year life, but caverns usually last longer. The SPR, with 60 storage caverns in four locations in Texas and Louisiana, is expected to be used as long as the nation wants strategic oil reserves. "Right now, it's indefinite," Bauer says.

After the Arab oil embargo of the early 1970s, the Department of Energy decided to develop underground oil storage to mitigate shortages. Borns says SPR originally used existing caverns, but they weren't ideal for long-term stability. The Department of Energy (DOE) asked Sandia to evaluate the concerns, and from that work Sandia developed computer models for the best ways to create caverns and to track how they change as fluids are injected over time, Borns says.

Sandia is SPR's engineering adviser, the research and development expert for geotechnology and fluid process engineering. Geotechnology relates to cavern stability, well stability and geologic processes such as subsidence. Fluid process engineering relates to leaching and oil chemistry. Oil in salt caverns starts out at surface temperature but heats up in the earth, altering

MEET Peter Swift

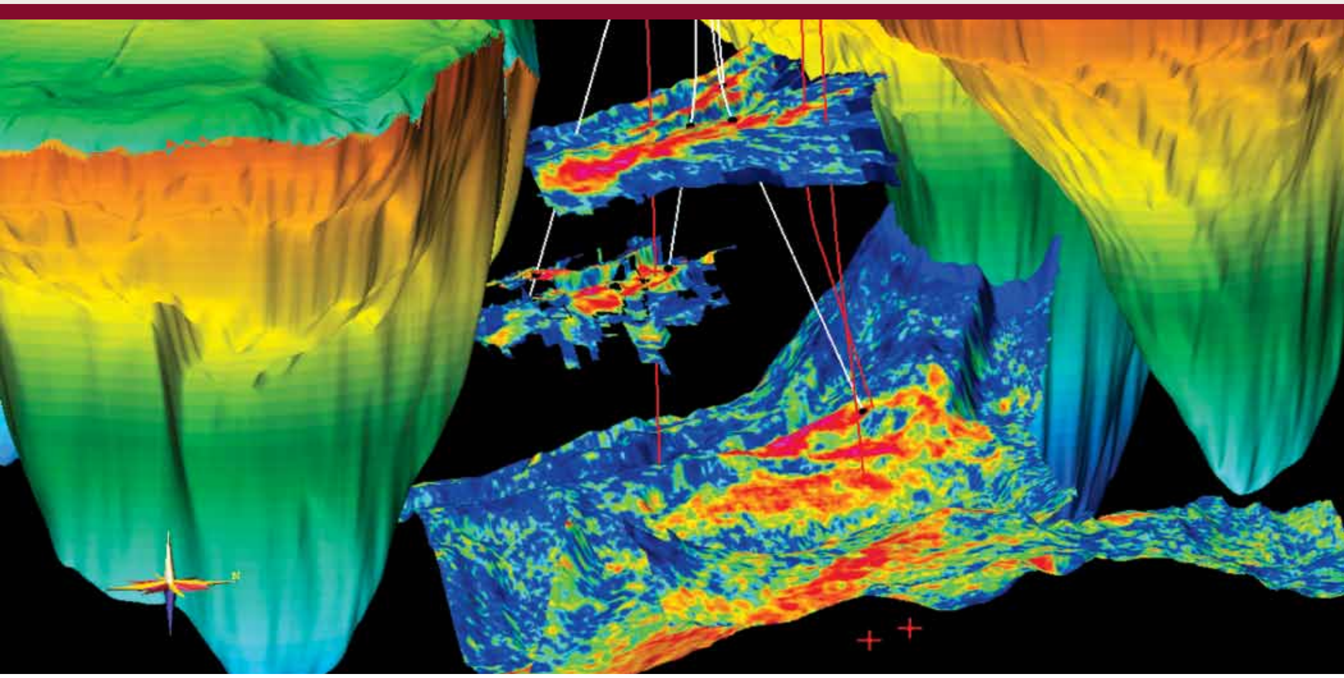
Swift came to Sandia in 1989 as a contract technical writer for the Waste Isolation Pilot Plant. Swift, now a Senior Scientist, became a regular staff member in 1993. He joined Sandia after several career changes. "I started here by answering a classified ad in the Albuquerque Journal that said, in its entirety, 'Wanted: scientist who can write.' At least that's how I remember it."

STATS

- Bachelor of arts in English from Yale University.
- Bachelor of science and master of science, both in geology, from the University of Wyoming.
- Ph.D. in geosciences from the University of Arizona. His dissertation research was on Early Proterozoic tectonics of southern Arizona.
- Swift worked in uranium, oil and gas exploration earlier in his career.
- He is a Fellow of the Geological Society of America.

Swift is national technical director of the Department of Energy Office of Nuclear Energy's Used Fuel Disposition R&D Campaign, after spending most of his Sandia career on two radioactive waste repository projects: WIPP and Yucca Mountain. He testified about the proposed, and now mothballed, Yucca Mountain project to a U.S. House of Representatives subcommittee in 2011.

A memorable project was helping write WIPP's compliance certification application to the Environmental Protection Agency in 1996. The application succeeded and WIPP opened. "We made a difference in something unprecedented," he says.



A Sandia modeling simulation shows a subsurface image of salt formations with incoming wellbores, or drill holes.

the vapor pressure and the amount of gas it can hold at pipeline pressures. "You have to understand how it's changing in order to make the oil suitable for the refineries when you draw it out," Borns says.

Bauer says Sandia took the lead in the 1980s on large-scale, three-dimensional modeling to analyze salt caverns and domes because it had codes and software to handle problems at that scale. 3-D lets researchers look at how an entire salt dome deforms. Bauer says it's so sophisticated that Borns' group models the behavior and response of each cavern simultaneously.

"Our models had to match things we could measure, such as the subsidence or how caverns are closing with time," Borns says.

Sandia began working on natural gas storage in salt caverns in the early 1990s, characterizing the salt and modeling for storage cavern design, Bauer says. Sandia also looked at specific gas properties as opposed to oil, since internal pressurization, thermal properties and pressure conditions are different. "By doing some of those early analyses we helped establish what kinds of pressure limits should be set in caverns," he says. ■

TIGHTER GRIP ON WASTE

The United States has been reviewing high-level waste disposal options since funding ended for Yucca Mountain in 2010. Hansen says the nation has ample granite formations, the rock Sweden and Finland want for their repositories; shale provinces, similar to what France and Switzerland are considering; and abundant salt.

The national repository program in the DOE Office of Nuclear Energy is evaluating the options. Sandia's Peter Swift is the technical director of the research and development program, in which nine national labs participate.

"From a science point of view, it's not an intractable problem," Swift says. "It's a pretty straightforward problem. Pick a good site, engineer a good set of barriers to go with it: the waste package, the seal system, the things that have to work with a well-chosen site to get the isolation. Those are the kinds of problems that we're good at."

The program is studying salt, crystalline or granitic rocks, mined repositories in clay and shale and deep borehole disposal about 2 to 3 miles underground. It won't recommend a specific disposal method, but instead conducts scientific studies to prepare for when the nation is ready to move forward, he says.

"The R&D challenge right now is to build the strongest technical cases we can at the generic level, anticipating that when we actually get to site-specific locations, geologic complexity will be much greater," he says.

Sandia's research includes studying whether salt formations such as those at WIPP can handle the extra heat from high-level waste or spent fuel, Swift says. Heating salt accelerates deformation and impacts the rate at which trapped water or brine moves — one of the things Sandia is examining, Swift says.

In 1980, the DOE began evaluating sites in different formations to store waste that has the highest radioactivity and generates the most heat. Yucca Mountain was selected by law in 1987, and Sandia eventually became the program's lead laboratory for repository science.

Swift says the site, taking advantage of the deep water table of Nevada's Basin and Range region, is the only one ever considered that's above a water table. The repository would have been mined low on the mountain, hundreds of meters below the surface. Plans called for an inclined ramp instead of a vertical shaft, so "you could basically drive a train right into the entrance" and bring in larger waste packages, Swift says. The design included engineered barriers against moisture with an extremely corrosion-resistant alloy capped by a titanium shield to keep the repository dry but allow ventilation. Sandia took the lead in preparing a license application to the Nuclear Regulatory Commission and was preparing for licensing hearings when Congress eliminated Yucca Mountain's funding. ■

A ROCK FOR ALL SEASONS

One rock type Sandia is studying as a waste-disposal alternative is shale, commonly called clay or mudstone. It's attractive for repositories because its high surface areas lend themselves to radionuclide adsorption and retard the movement of contaminants should they escape, says geomechanics researcher Tom Dewers. The higher the surface area, the greater the adsorption of contaminants.

Shales are the most abundant and widely distributed sedimentary rocks, but the least studied. Tiny grain sizes and pores make them difficult to study with optical microscopes, and they erode easily and don't stand out in geologic outcrops, Dewers says.

But, he says, they're important because "they exert a fundamental control on fluid flow in sedimentary basins and they're fundamental in hydrocarbon trapping."

Research includes simulation at atomic scales to study such things as absorption and water-rock interactions that retard contaminants, Dewers says. Sandia also studies shale for hydrocarbon or petroleum reservoirs and carbon sequestration.

"The fundamental thing that makes shales a special rock type for all of these applications is the low permeability because of the tiny pore spaces," Dewers says. "The low permeability lends itself to sealing in a repository setting, lends itself to maintaining the waste packages in place should any leakage occur. It provides the sealing mechanism to minimize escape routes for subsurface CO_2 as it migrates up."

Mudstones also have gained importance because of shale gas. Dewers' research concentrates on shale gas for energy security.

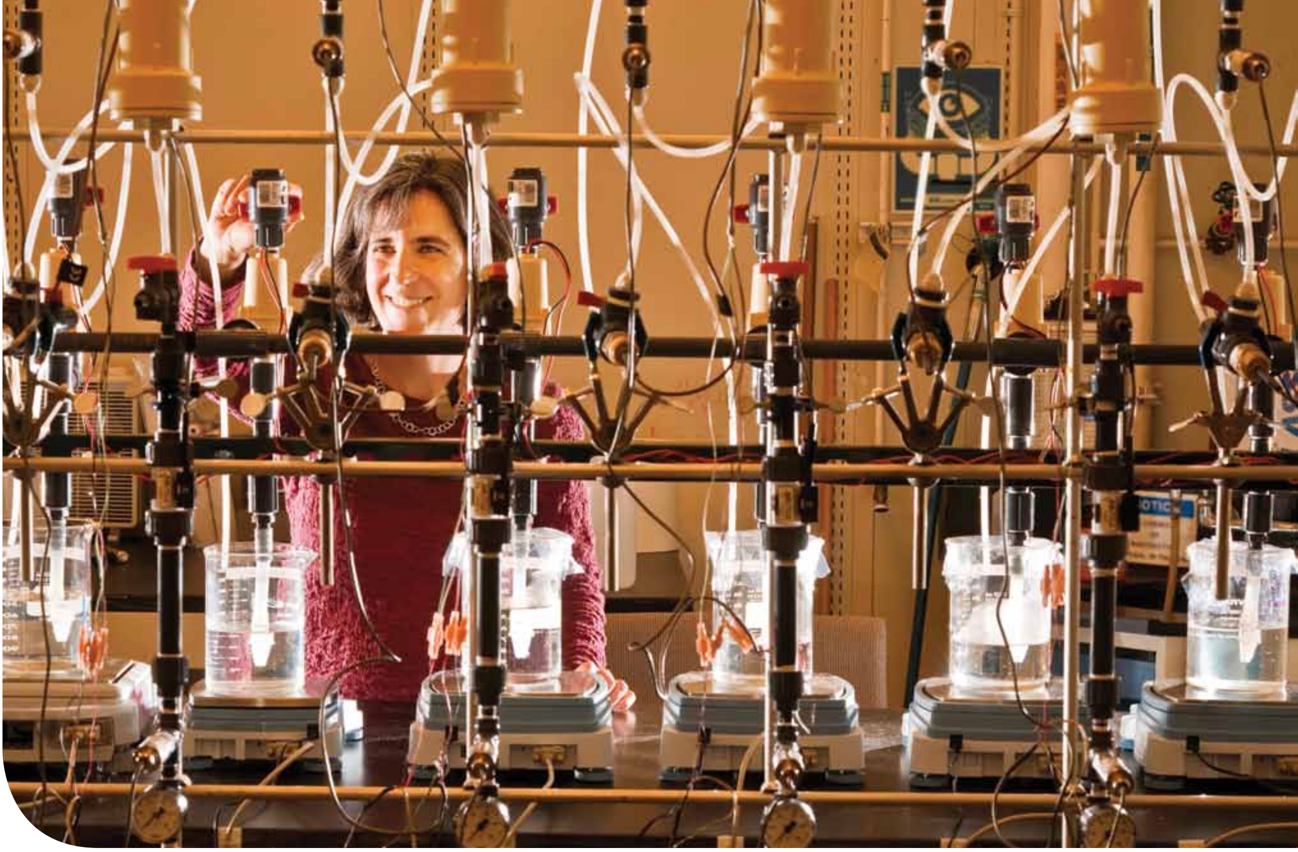
The nascent shale gas industry is focused on producing rather than on how to sustain production, he says. Because of Sandia's broad expertise and multidisciplinary approach that includes everything from high-performance computing to experimental facilities, it can study how to predict production declines and how to extract more gas, Dewers says.

"You can only drill so many holes," he says. "There's a lot of shale gas out there but you're leaving 90 to 95 percent in place. You're not going to be able to get all of it but if you can get a 5 percent increase, a 10 percent increase, that can make a huge difference in the industry across the nation and over decades."

The tiny pore spaces and low permeability that make mudstones attractive as reservoirs create geoengineering difficulties, Dewers says. Sandia works on the problem by imaging those tiny pore spaces to understand nanoscale controls on fluid migration.

Sandia's Materials Characterization and Performance Group does focused ion beam scanning electron microscopy, "just the right resolution for looking at these pore systems," Dewers says. "We can image those pore spaces in three dimensions. We have tiny building blocks of what makes up these rocks." Then, researchers can study how to scale up the physics from the nanoscale to the engineering scale, he says. ■

Geomechanics specialist Tom Dewers removes a shale sample from a high-pressure test vessel in a Sandia geosciences lab. Shales are abundant and important because their tiny pores produce low permeability. "The low permeability lends itself to sealing in a repository setting," Dewers says.



CAPTURING CARBON DIOXIDE

Mudstone has a role as a caprock for carbon sequestration reservoirs. Sandia geochemist Susan Altman (shown at work in the photo above) views sequestration as part of the solution for ever-increasing carbon emissions. The goal is to capture CO_2 from power plants, then put the carbon underground to keep it out of the atmosphere.

But that raises questions: Can we safely put it underground and what's the impact?

Sandia and the University of Texas at Austin work on carbon sequestration together as the Center for Frontiers of Subsurface Energy Security, a program begun in August 2009 and funded by DOE's Office of Basic Energy Sciences. Both institutions bring unique facilities and staff to a multidisciplinary approach that includes chemistry, microbiology, geomechanics and geophysics. That approach studies the problem from the atomic scale to the regional scale and performs both small-scale lab experiments and field work, Altman says.

The research focus is on deep saline aquifers. The center is studying sandstones for sequestration because they have more pore space and their quartz grains have less reactive surface area. "When considering the rock you have to consider the reactive surface because the CO_2 is going to be very reactive to whatever the solid is. You also have to think about potential of the CO_2 to escape so you have to consider trapping by the caprock," Altman says. Sequestration can't be done in areas with potential economic resources, which is why researchers focus on deep saline aquifers where water is too salty to drink.

Researchers, using the unique facilities of Sandia's geomechanics laboratory, measure the strength of different heterogeneous caprock materials, both to better understand under what conditions the caprock will fracture and to validate the solid mechanics model, called Kayenta, developed at Sandia. From this information, coupled injection, multiphase flow and geomechanics simulations are being run to predict how leakage pathways develop in jointed caprock.

There are pilot studies worldwide to put carbon underground. There also are natural reservoirs — carbon dioxide formed from volcanic processes that remains underground tens of thousands of years later, Altman says. The center is "trying to understand how long it's been underground and what characteristics of the geology have prevented leakage."

Some basic science aspects of CO_2 storage are well understood, and predictive computer models are developing to deal with the complicated chemical and geomechanical interactions. "Also, for some processes, understanding what's happening at the small scale, the atom, helps to make a prediction of what will happen at the large scale," Altman says. ■

SINKHOLE SOS

The U.S. Geological Survey turned to Sandia National Laboratories for help when the earth opened up near Bayou Corne, La.

Sandia geotechnology and engineering manager Dave Borns joined a scientific advisory panel that provided technical evaluations within days of the sinkhole that formed when a cavern collapsed in the Napoleonville Salt Dome in Assumption Parrish. He later became part of a Blue Ribbon Commission after the Bayou Corne community was evacuated.

The USGS had been keeping an eye on the area because of harmonic tremors that began in June 2012. Gas bubbled up at different locations in the wetlands of Bayou Corne and nearby Grand Bayou. The sinkhole opened overnight on Aug. 2, 2012, off the western edge of the salt dome.

It grew to roughly 1.5 miles across and about 500 feet deep by July 2013, Borns says.

The Louisiana Governor's Office of Homeland Security and Emergency Preparedness asked the U.S. secretary of energy for help from Sandia, which previously worked on cavern collapse and sinkhole formation problems on Weeks Island, La. The request noted Sandia's "advanced understanding and knowledge in salt cavern construction, stability and operation."

"Sandia has almost 40 years of experience in salt and salt mechanics and 30 years of experience with the Strategic Petroleum Reserve caverns and stability as it relates to them," Borns says. SPR's storage caverns lie in salt formations in Texas and Louisiana.

Louisiana Gov. Bobby Jindal established the Blue Ribbon Commission to create standards to allow homeowners to return to Bayou Corne. He also asked the energy secretary to add Sandia to the incident science team, the Bayou Corne Science Workgroup.

Borns was tapped to join the commission, which formed two groups: gas releases and cavern stability. Sandia is part of the stability group, with Borns as head of its subsidence study program. While the gas release group tried to control gas flowing into homes, the long-term issue is the area's stability, he says.

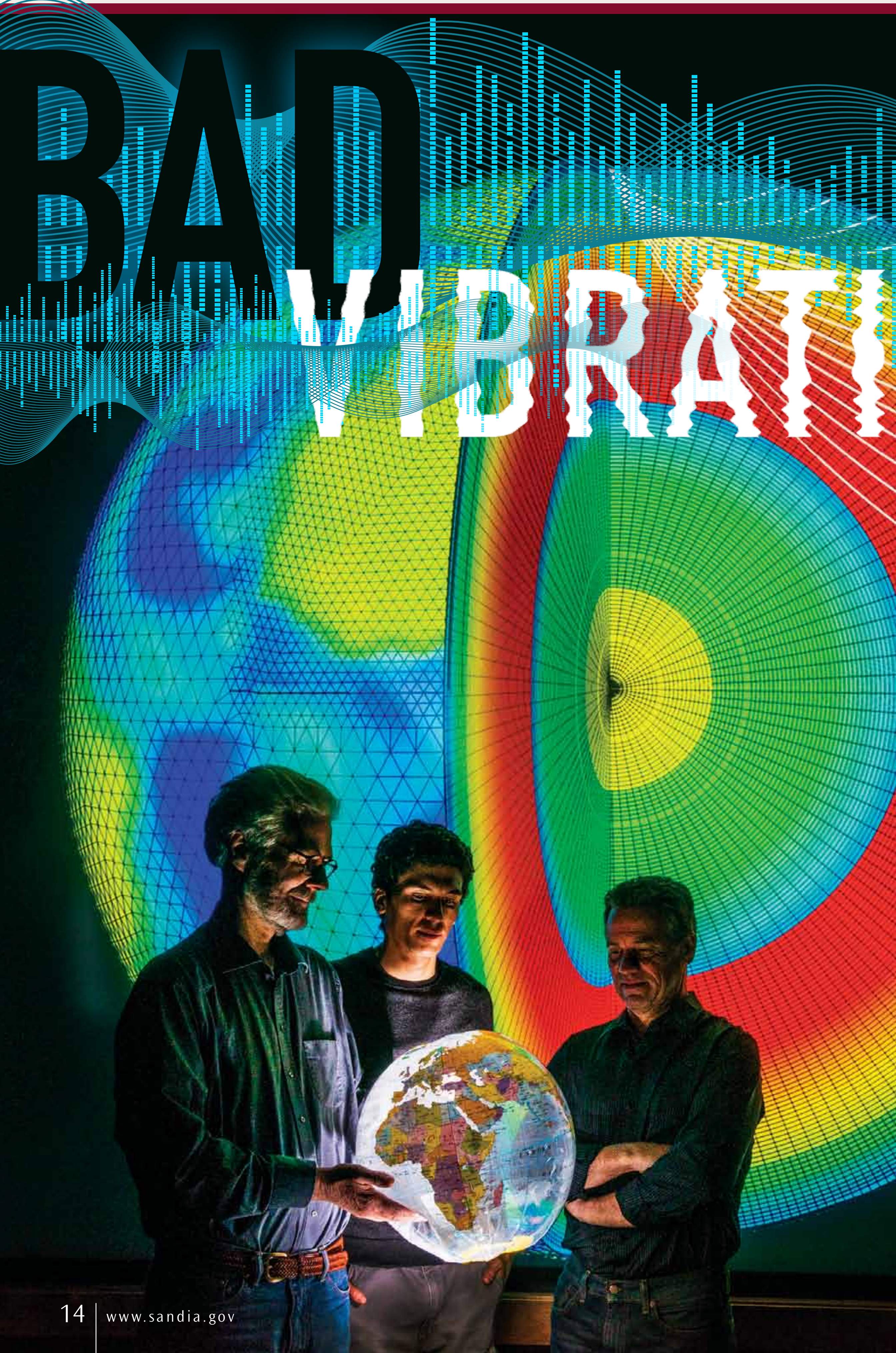
This Aug. 3, 2012, aerial photo released by the Louisiana Department of Natural Resources shows the sinkhole near Bayou Corne, La., which has grown since it first began forming. Sandia researcher Dave Borns is among the experts providing technical evaluations on the sinkhole.

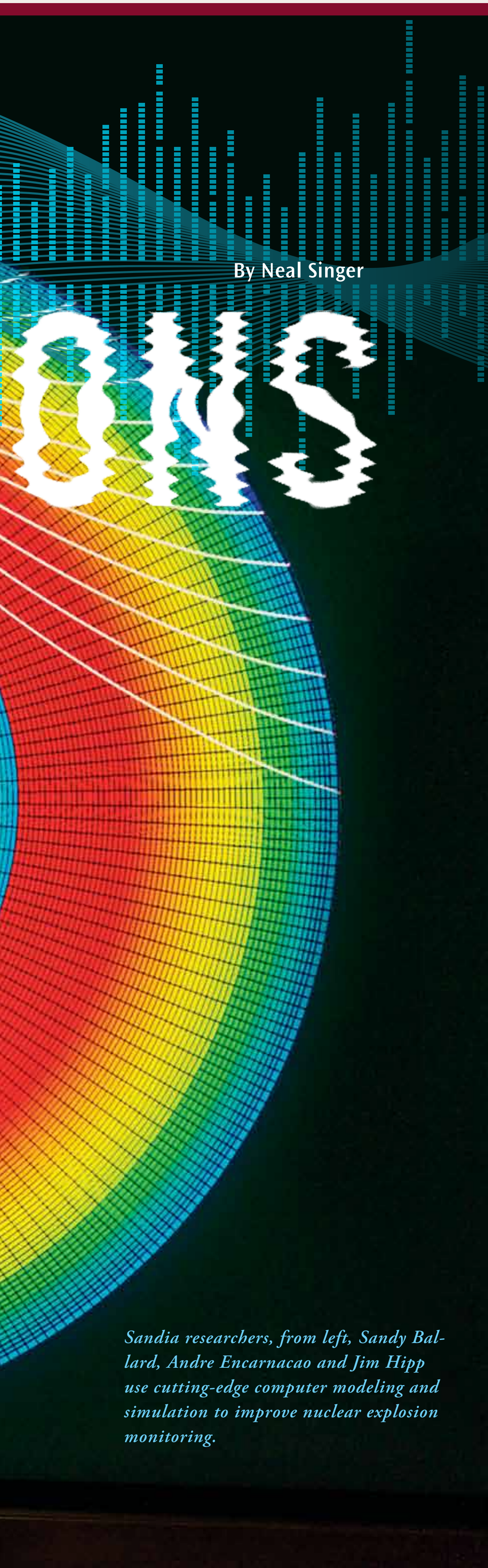
Subsidence studies measured surface levels around the caverns and the sinkhole, using both standard surveying methods and satellite imagery. Changes in surface levels are good monitors of subsurface deformation and allow scientists to see how the process that led to the cavern collapse and the sinkhole are either continuing or slowing down, Borns says.

"We try to add our support by adding expertise to federal and local governments when they're faced with understanding technical issues that impact their resources," Borns says. ■

— Sue Major Holmes

BAD VIBRATI





By Neal Singer

Sandia researchers, from left, Sandy Ballard, Andre Encarnacao and Jim Hipp use cutting-edge computer modeling and simulation to improve nuclear explosion monitoring.

Tracking illegal nuclear tests is getting harder as explosions quiet down. **GEOSCIENTISTS ARE MEETING THE CHALLENGE** using sophisticated computing, signals and sensing to better hear the rumble.

The Earth is noisy. Thousands of sound waves travel it daily, sent on their ways by underground fractures and slides. Ocean waves intersecting the atmosphere create white noise of their own.

Cutting through these impediments and more, the Comprehensive Test Ban Treaty Organization, headquartered in Vienna and supported in part by Sandia's technical expertise, is charged with rapidly identifying and locating the source of any nuclear detonation, whether under, on or over the ground.

That task has grown more difficult recently. In the era of the Soviet-U.S. standoff, it would be a dull sensor that could miss the equivalent of millions of tons of TNT exploding instantaneously. But new wannabes to the nuclear club may create explosions more difficult to detect, weaker even than the first nuclear explosions in 1945. If these impacts aren't recorded, testing could continue outside the spotlight of world opinion.

Fortunately, detection expertise has grown ever greater over the decades, says Sandia manager Tim McDonald.

"The idea is to combine computing, signal processing, and sensors to achieve the goal of making it impossible to explode a nuclear weapon anywhere in the world without it being sensed," McDonald says. "Sandia is very much a leader in this."

While Sandia routinely assists the National Data Center, "we're also exploring work with the International Data Center to help them do as good a job as they can. It's in our national interest," he says.

One technique the United States and much of the world uses to track nuclear explosions is infrasound — pressure waves travelling at frequencies below the ability of humans to hear them. These waves, discovered in the 19th century, made it possible for scientists to deduce the location and power of volcanoes because the waves remained significant enough for detection by barometers, even after travelling thousands of miles.

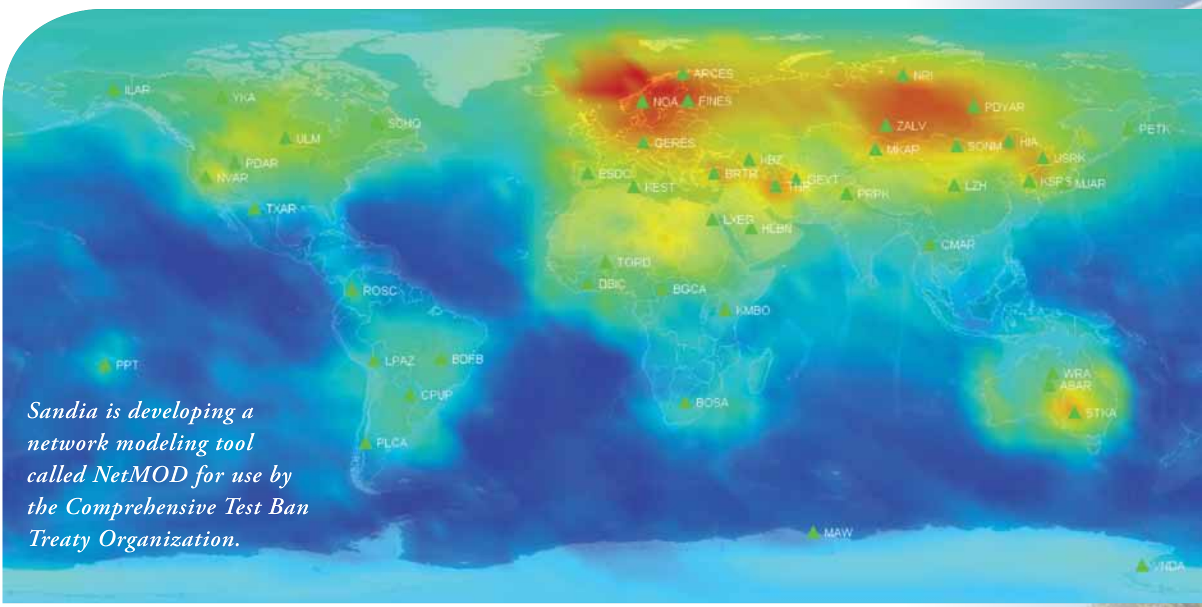
In the 1960s, more advanced infrasound sensors provided information about the location and power of nuclear tests. Today, for nations without access to satellites or the ability to monitor underground (seismic) signals, the method remains a primary technology in detecting nuclear explosions.

That the U.S. works to improve the relatively low-tech method is not just a matter of keeping up with the Smiths, says Kyle Jones, a Sandia master of infrasound. "What happens if [a nuclear] event occurs on a cloudy day? Infrasound would be better than satellite monitoring. And if it took place in the air, seismic stations would need to be stationed improbably close because energy doesn't couple well to the ground."

Politically, says Sandia researcher Eric Chael, "the U.S. has an interest in knowing what the international community is seeing and saying about events like the big bolide explosion over Russia in February." Infrasound was peculiarly suited to its role as the world's ears for that atmospheric event.

Still, infrasound has its own weakness: It works better downwind than upwind, since wind can greatly weaken an infrasound signal.

Since there is no easy, single answer to monitoring the world's nuclear explosions, Sandia researchers work with a number of labs to improve infrasound techniques. "We test commercial infrasound technology, provide feedback, and develop and improve algorithms," Jones says. "The ongoing work has reduced the error in location finding significantly." But the meat and potatoes of U.S. nuclear explosion monitoring in the era of below-ground testing, whether announced or clandestine, remains seismic – the monitoring of underground pressure waves.



Sandia is developing a network modeling tool called NetMOD for use by the Comprehensive Test Ban Treaty Organization.

By setting up stations around the world with the permission of host governments, monitors can compare notes on the pressure waves they monitor. The waves from nuclear events have unique characteristics that can be measured.

While the method seems simple, complications arise because the Earth is made of various materials which slow, speed up or deflect waves, changing the intensities and arrival times of their signals.

Engineers Darren Hart, left, and Kyle Jones set up a sensor system at Sandia Labs that lets operators detect underground or near-surface nuclear explosions. Signals from these large events can travel thousands of miles through the earth or atmosphere.

Says Sandia researcher Sandy Ballard, “To get more accurate predictions of travel times of seismic waves, we developed a three-dimensional model of the Earth that can predict travel times more accurately and thus locate events more accurately, with smaller error ranges.”

Sandia is evaluating the method for accuracy. Thus far, it has proved significantly more accurate than other models. Predictions are checked by comparing them with observed travel times of actual waves.

“A lot of software goes along with it,” says Ballard.

When will model be publically released? “We work for the U.S. government and will give it to the international system when it’s OK to do so,” he says. Meanwhile, Sandia helps develop more sensitive seismometers and place more of them over the Earth. “Instead of one instrument that measures three components of motion, each instrument now has a single function and is placed in an array — say 20 of them in a circle tens of kilometers across — so we can detect smaller and smaller seismic waves,” Ballard says. ■

Energy, climate and two poles

By Neal Singer

While the country debates global warming, Sandia researchers are collecting cloud and climate data from out-of-the-way places and novel sources, and putting that data into faster, more complex computer models that will help society make effective choices.

"Our examination of atmospheric greenhouse gases, black carbon [particulate carbon] and aerosols in the Arctic will tie into choices about energy use," says Sandia researcher Mark Ivey, who manages the U.S. Department of Energy's climate research facility in Alaska, 320 miles north of the Arctic Circle. "There's a big shift into natural gas, and in the short run that could have a net benefit by replacing dirty coal. But we need to know, in the long run, how energy choices we make affect the atmosphere and climate."

Because changes show up fastest in environments with snow and ice, Sandia has an interest in monitoring the Antarctic as well, Ivey says. "Our preference is to incorporate both poles in our planning. There's a lot of important atmospheric and climate science that needs to be done in Antarctica and the southern oceans."

His instruments measure clouds, visible and infrared radiation, wind and concentrations of various gases, while proposed aerial vehicles will make atmospheric measurements very close to the North Pole that are needed by climate models.

Less dramatically but equally important, Hope Michelsen and colleagues at Sandia's California lab gather data from land-based mobile laboratories. "The DOE has a handful of sites around the world to understand climate," she says. "Oklahoma is the biggest site. We had a mobile lab there to understand CO_2 emission. Now it's here in California."

Michelsen wants to know what sources produce climate-affecting gases, such as CO_2 and methane, as well as particulates like black carbon (soot). "These species cycle in and out of the atmosphere," she says. "How do you determine how big the source is and where the problem gasses are coming from?"

Black carbon, which absorbs solar radiation, is of particular interest to Michelsen. While the most obvious sources of atmospheric soot are forest fires and electric power plants, 30 percent comes from diesel engines, but their emissions are masked by the size of the particles. "The particles are harder to see than they used to be because soot particles from modern engines are small, but they're still there," Michelsen says.

At her home base at Sandia's Livermore site, emissions from San Francisco and San Jose are blown in by the wind and measured by tools she and her team are devising. "We feel we need to understand the sources on a regional scale. If we ever have a climate treaty, we need to understand the sources of our pollutants."

Such data is useful in high-resolution climate models. New programming by Sandia researcher Mark Taylor's team produce two simulated years of atmospheric changes per day of computation. It takes just 25 days to perform a 50-year simulation, the time spectrum preferred by climate scientists. The model simulates changes in temperature, pressure, moisture, CO_2, aerosols, smoke and other measures over a world divided into chunks of area as small as 12 kilometers.

Like weather forecasts, climate models have improved over the years, but need more details of processes like radiation, clouds and convection that are accurate only to about 100 km. Researchers are improving the way they model such physics processes to take advantage of the new high-resolution atmospheric model.

"With our work and DOE's Titan supercomputer, we now have the world's fastest high-resolution model of the atmosphere," Taylor says. The architecture of the supercomputer at Oak Ridge, Tenn., is based on Sandia's groundbreaking Red Storm supercomputer. The atmosphere component of the climate model uses core software developed at Sandia.

"Before our work on the new core software, we didn't even consider such resolutions because they would take so long," Taylor says. "Now we can." ■

MEET

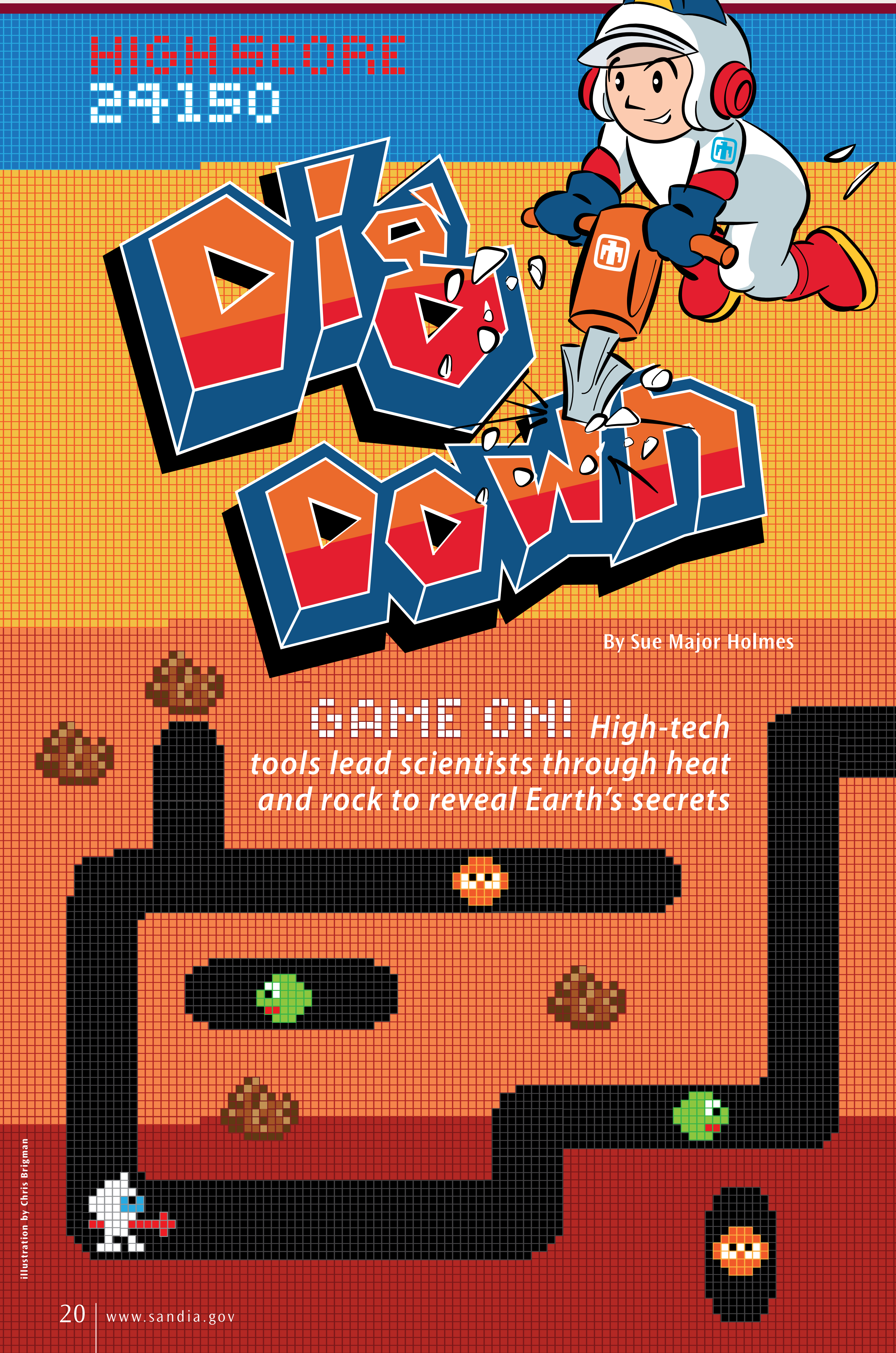
Hope Michelsen

Michelsen quiets her mind with yoga. The exercises build strength, flexibility, balance and, above all, concentration so intense that the ordinary stresses of work vanish for the hour she team-teaches the ancient discipline at Lawrence Livermore National Laboratory, across the street from her Sandia office. "I started yoga with a class there 11 years ago," she says. "It's nice to give back, and it's a nice way to meet people from the other lab." The lunchtime class averages 15 students. "I break away and let all the tension out." Michelsen also tends to her two border collies. "They are extremely smart," she says. "Not only do they pick up the daily newspaper from the front drive and bring it to me, but I tell them that their feet are dirty and they get in the shower. They seem to understand a huge amount of what I say."

STATS

- Bachelor's degree in chemistry with high honors from Dartmouth College.
- Ph.D. in chemistry and physics from Stanford University.
- As a Stanford graduate research assistant she studied the interactions of molecules with metal surfaces and how energy transfer occurs between gases and solids.

Michelsen was a postdoctoral researcher at Harvard studying stratospheric chemistry to understand the causes of the Antarctic ozone hole and ozone loss at high altitudes at all latitudes. She joined Sandia's technical staff in 1999 after working with Atmospheric and Environmental Research Inc., where she investigated the influence of aerosol-mediated chemistry on stratospheric ozone abundance at mid-latitudes.

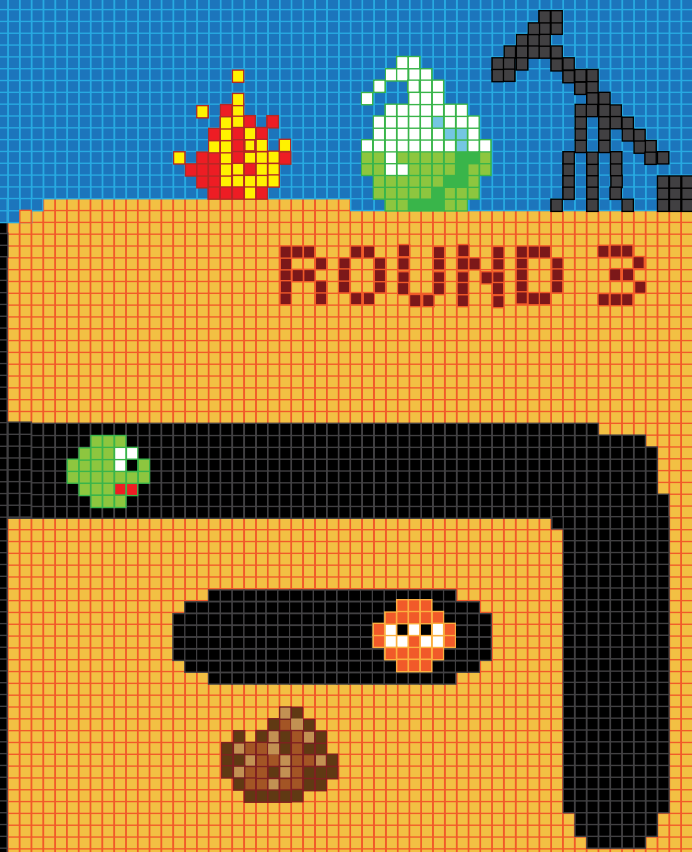


Dig Down

By Sue Major Holmes

GAME ON! *High-tech tools lead scientists through heat and rock to reveal Earth's secrets*

illustration by Chris Brigman



Fathoming the earth calls for instruments for the most unforgiving environments.

Sandia has a history of using instruments in less-than-ideal conditions. Its research on geoscience tools traces back to decades of developing monitoring instruments for the nation's underground nuclear testing program that ended in 1992. It now works on instruments for high-temperature, high-pressure geothermal environments, emerging technology such as rotational seismometers and tools needed in drilling, diagnostics and transmitting data.

"What makes Sandia successful in this arena is our ability to sustain research and development over numbers of years," says Geothermal Research Department manager Doug Blankenship. And, he says, Sandia has a sweeping range of expertise.

The high-temperature electronics industry turns to the department to independently test and evaluate instruments or parts because of Sandia's history designing useful tools and developing prototypes, says the department's Scott Lindblom.

"It seems like we've always got somebody's new widget in an oven, looking at how it works. … We like to test for extended periods and make sure things are reliable," he says.

Research into instruments to be used in wellbores, or downhole, is concentrated on the geothermal industry, says Geosciences Research Foundation Lead Director Marianne Walck. That effort tests everything from electronics, pressure vessels and seals to connections on circuit boards and soldering techniques for instruments under pressure and facing temperatures as high as 600 degrees Fahrenheit.

Well-logging instruments and other monitoring tools give an idea of a borehole's geophysical properties during drilling and provide key performance measurements to maximize bit life.

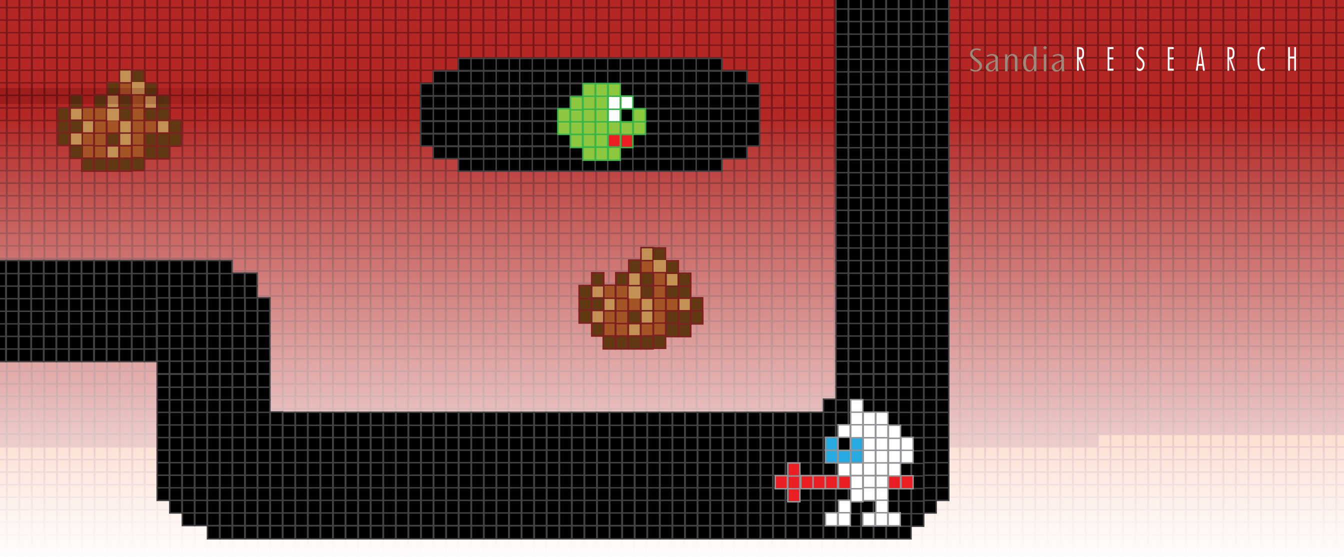
High-temperature tools

Researchers are developing a high-temperature diagnostic tool to measure underground fractures between wells. Engineers and scientists currently evaluate geothermal reservoirs by pumping a chemical tracer into one well and measuring how much arrives at the surface of a second.

But surface measurement can't tell where the tracer entered the well. "You can have multiple fracture zones and you don't know which zone is producing that tracer," Lindblom says. Geothermal researchers, working with Sandia experts who developed microfabricated chemical detection technology, are designing a tool geochemists can lower into the hole and slowly raise through fracture zones to measure the most productive ones, he says. The project also involves Sandia's Materials Science and Microsystems Science Technology & Components centers.

Sandia for years has studied ways to retrieve data from the bottom of a hole. It won a prestigious R&D100 award in 2003 for acoustic telemetry, now a commercial technique. Rather than sending pulses through drilling mud, acoustic telemetry uses drilling pipe as the conduit and sound waves to carry data — what Blankenship likens to banging on the pipe itself.

Now Sandia is working on a high-temperature tool to convert electrical signals from a downhole instrument into an optical signal that sends data up to the surface over high-temperature fiber optic cable, he says. The drilling world became



Technologist Elton Wright shows a torsional spring used to simulate the rotational vibration of a drill string.

interested in fiber optic cable relatively recently because it transmits huge amounts of data compared to standard electrical wire.

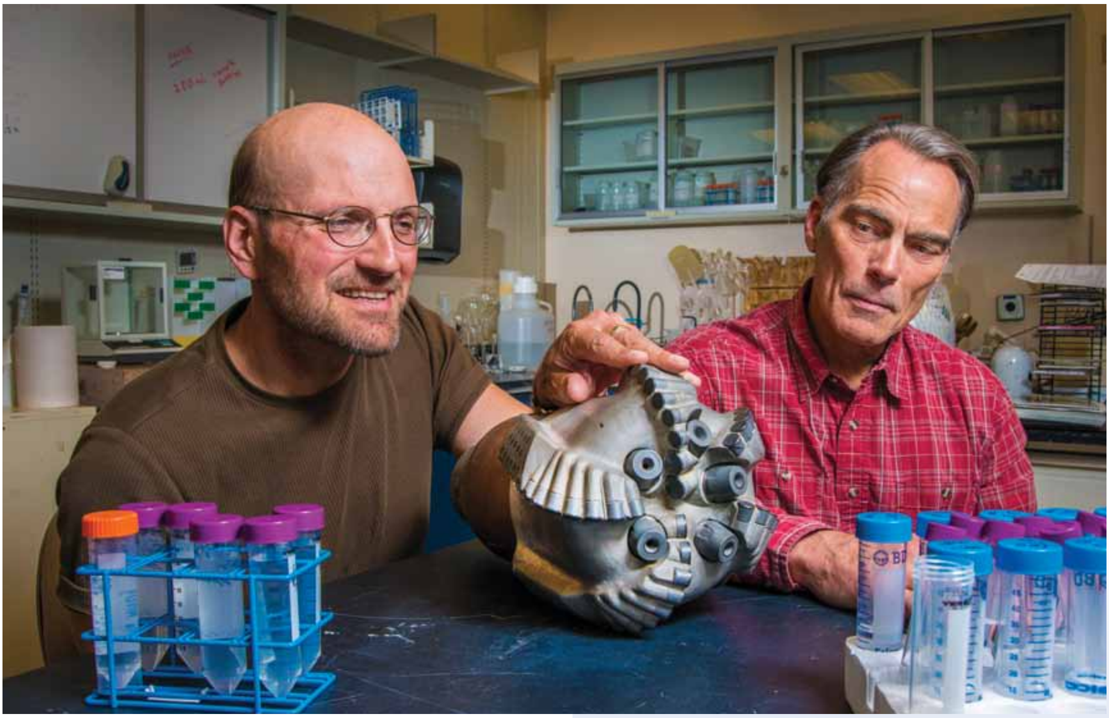
"You can build a really great high-temperature tool that generates a whole bunch of useful data, but if you can't get it back to the surface in a reasonable amount of time it's actually not that useful," Blankenship says.

Optical fiber also offers improved ways of sensing. A single fiber optic cable the length of a well could allow drillers to read temperatures every meter. But when such systems were deployed in the late 1990s, they failed. Hydrogen in the wells was blamed.

Sandia, in a blind study exposing fibers from different companies to hydrogen at high temperatures, found even small amounts had detrimental effects. Companies have since developed hydrogen-resistant fibers, and Sandia is again testing their fibers against hydrogen. Researchers can measure many fibers simultaneously in one pressure vessel, doing more comprehensive tests than industry labs can do on their own, Lindblom says.

Sensing mechanisms for rotational seismometers

Another example of Sandia's work on unique instruments is the development of rotational seismometers, particularly for geothermal applications. Traditional seismometers used to monitor earthquakes or verify underground nuclear test treaties measure translational ground motion (up-down, east-west and north-south). Rotational seismometers measure the rotation about those axes, which more fully describes the motion, says Rob Abbott of the Geophysics and Atmospheric Sciences Department, who is leading the research. The instrument is sensitive to a twisting motion rather than motion along a particular direction.



In the photo above, engineers Pat Brady, left, and Bob McKinnon look over a state-of-the-art drill bit used in deep boreholes. Left, Elton Wright works on a prototype bit used in Sandia's Hard-Rock Drilling Facility.

Putting rotational and traditional seismometers together in what Abbott calls a point seismic array would offer much more information and could eliminate the need for multiple traditional sensors in some cases.

The research effort focuses on three separate sensing mechanisms.

A project under the Department of Energy's Office of Energy Efficiency and Renewable Energy, in partnership with a private company, is aimed at monitoring micro-earthquakes in geothermal hydraulic stimulation experiments, Abbott says. The sensor uses magneto-hydrodynamics, in which metallic fluid in a cavity moves when hit by the rotational seismic wave and a sensor picks up the movement to grasp what the ground is doing, he says.

Sandia also is working with a major oil company to develop an instrument using microelectromechanical systems under a Cooperative Research and Development Agreement. And a Laboratory Directed Research and Development project, atomic interferometry, uses quantum mechanics to measure seismic rotations by dropping clumps of cold cesium atoms that get in the way of each other to create a quantum wave interference pattern, Abbott says. ■

Sandia has experience using instruments in less-than-ideal conditions, such as at the U.S. Department of Energy's Atmospheric Radiation Measurement climate research facility at Barrow, Alaska.

Computer power clicks with geochem

By Nancy Salem

Radioactive waste disposal worries people. They want to know where contamination might end up and how it can be kept away from drinking water.

"Very little is known about the fundamental chemistry and whether contaminants will stay in soil or rock or be pulled off those materials and get into the water that flows to communities," says Sandia geoscientist Randy Cygan.

Researchers have studied the geochemistry of radioactive materials or toxic heavy metals like lead, arsenic and cadmium. But laboratory testing of soils is difficult. "The tricky thing about soils is that the constituent minerals are hard to characterize by traditional methods," Cygan says. "In microscopy there are limits on how much information can be extracted."

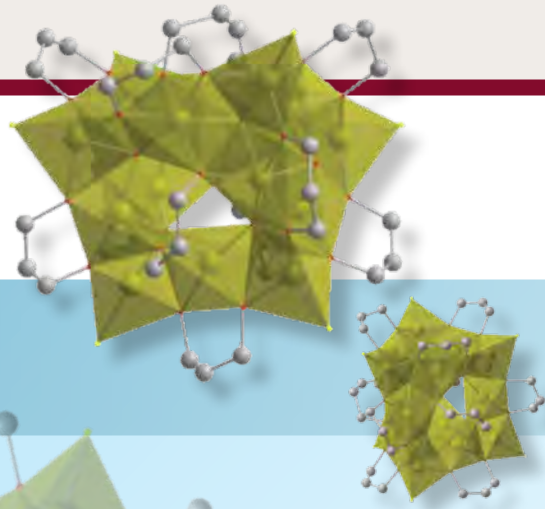
Cygan says soils are mostly made up of clay minerals with ultra-fine grains less than two microns in diameter. "That's pretty small," he says. "We can't slap these materials on a microscope or conventional spectrometer and see if contaminants are incorporated into them."

Cygan and his colleagues instead are developing computer models of how contaminants interact with soil and sediments. "On a computer we can build molecular models that let us test viable mechanisms for how contaminants interact with the mineral surface."

He describes clay minerals as the original nanomaterial, the final product of the weathering process of deep-seated rocks. "Rocks weather chemically and physically into clay minerals," he says. "They have a large surface area that can potentially adsorb many different types of contaminants."

Clay minerals are made up of aluminosilicate layers held together by electrostatic forces. Water and ions can seep between the layers, causing them to swell, pull apart and adsorb contaminants. "That's an efficient way to sequester radionuclides or heavy metals from ground waters," Cygan says. "It's very difficult to analyze what's going on in the interlayers at the molecular level through traditional experimental methods."

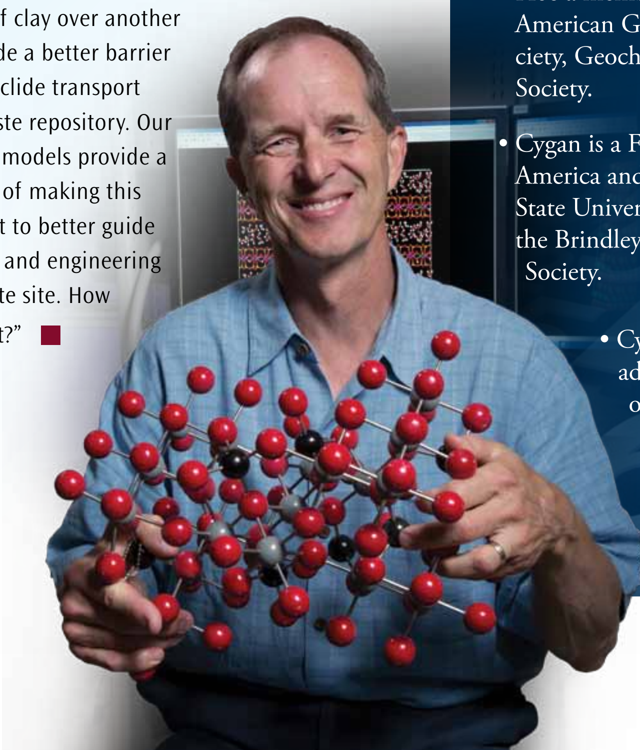
Molecular modeling describes the characteristics and interaction of the contaminants in and on the clay minerals. Sandia researchers are developing the simulation tools and the critical energy force field needed to make the tools as accurate and predictive as possible. "We've developed a foundational understanding of how the clay minerals interact with contaminants and their atomic components," Cygan says. "That allows us to predict how much of a contaminant can be incorporated into the interlayer and onto external surfaces, and how strongly they bind to the clay."



mistry

The computer models quantify how well a waste repository might perform. “It allows us to develop performance assessment tools the Environmental Protection Agency and Nuclear Regulatory Commission need to allow them to say, technically and officially, ‘Yes, let’s go ahead and put nuclear waste in these repositories.’”

Industry and government also use molecular modeling methods to determine the best types of waste treatment and mitigation. “We’re providing the fundamental science to improve performance assessment models to be as accurate as possible in understanding the surface chemistry of natural materials,” Cygan says. “This work helps quantify how strongly or weakly uranium, for example, may adsorb to a clay surface, and whether one type of clay over another may provide a better barrier to radionuclide transport from a waste repository. Our molecular models provide a direct way of making this assessment to better guide the design and engineering of the waste site. How cool is that?” ■



MEET

Randy Cygan

Cygan is an avid cyclist. Growing up in Chicago he biked throughout the city, exploring its unique architecture and the beaches along Lake Michigan. In graduate school at Penn State his bike rides were often followed by building computer codes to model the physics of bicycle motion down the steep hills surrounding the campus. Cygan goes on week-long bike tours in different parts of the country. He finds biking on back roads clears his mind and helps him generate new modeling ideas.

STATS

- Bachelor of science in chemistry from the University of Illinois at Chicago.
- Master of science and Ph.D. in geochemistry and mineralogy from Pennsylvania State University.
- As a Senior Scientist in the Geoscience Research Group at Sandia Labs, Cygan specializes in applications of molecular simulation and various spectroscopies to understand mineralogical, geochemical and materials behavior.
- Cygan is the author of more than 100 technical journal articles and several hundred conference presentation abstracts.
- He’s a member of the American Chemical Society, American Geophysical Union, Clay Minerals Society, Geochemical Society and Materials Research Society.
- Cygan is a Fellow of the Mineralogical Society of America and a Centennial Fellow of Pennsylvania State University, and was recently presented with the Brindley Lecture Award by the Clay Minerals Society.
- Cygan has also contributed to numerous advisory boards and society committees, organized conferences and workshops, served as an associate editor to several journals and co-edited a book on molecular modeling of geochemical systems.

Sandia

RESEARCH

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LOOKING BACK

People believed in the late 1970s that America could run out of natural gas in less than 10 years.

So Sandia Labs researchers helped develop ways to induce fractures in underground rock and release natural gas. The cracks could be propped open to let gas flow through new pathways.

The early Sandia experiments involved "drilling a hole, putting gas into it and igniting the gas," says labs geologist Dave Borns. The explosions showed the shape of the initial fracture, an important consideration in maximizing gas availability.

Techniques soon shifted from gas explosions to "hydrofracking," or pumping water underground at increasing pressures to create tiny fractures that freed encapsulated gases.

Sandia researchers led by Norm Warpinski, now retired, adapted earthquake seismology into a technique called microseismic monitoring. It better mapped the extent and direction of tiny, induced subsurface fractures and was a breakthrough in freeing the clean-burning fuel.

"We've had senators from all over the country recognize Sandia's contributions," Borns says.

Because water is a limited resource, Sandia researchers are returning to gas ignition to induce fractures. An induced gas explosion won't ignite gases trapped in the rock, because they can't flow to the ignition point until the fracture is created.

The work has helped expand the known natural gas reserves to 70 years.

— Neal Singer

Work on drill bit technology and down-hole sensors by Sandia engineers including Joe Henfling, left, and Randy Hermann has helped advance the science of unlocking natural gas.